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SUMMARY

1. PURPOSE. To provide security and policy review on the document at Tab 1 prior to release to the public.

2. BACKGROUND.
Authors: Boris V. Zhdanov, Matthew D. Rotondaro, Michael K. Shaffer, and Randall J. Knize

Title: Efficient potassium Diode Pumped Alkali Laser operating in pulsed mode

Document type: paper for submission to "Optics Express" journal

Description: In this paper the authors present results of experiments on development of the hydrocarbon free alkali laser.

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Previous Clearance information: None

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CORY T. LANE, Lt. Col., USAF
Director of Research
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Tabs
1. Manuscript
2. Letter from funding organization (HEL JTO)

Efficient potassium Diode Pumped Alkali Laser operating in pulsed mode

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Abstract: This paper presents the results of our experiments on development of the efficient hydrocarbon free Diode Pumped Alkali Laser based on potassium vapor buffered by He gas at 600 Torr. A slope efficiency of more than 50% was demonstrated with total optical efficiency about 30%. Such result was achieved by using a narrowband diode laser stack in pulsed mode as a pump source that allows to avoid limiting thermal effects and ionization.

OCIS codes: (140.1340) Atomic gas lasers; (140.3480) Lasers, diode-pumped.

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1. Introduction

Since the first demonstration of an efficient optically pumped alkali laser in 2003 [1], and after the first Diode Pumped Alkali Laser (DPAL) demonstration in 2005 [2], significant progress in DPAL development and power scaling was achieved. The most impressive results were achieved with Cs and Rb DPALs [3 - 5] including the demonstration of 1 kW output

power with optical efficiency about 50% in CW regime for Cs DPAL [6]. Also, power scaling experiments with multiple diode laser pump sources [7 - 9] were performed, including experiments with transverse pumping [8] and an unstable cavity [9]. On the other hand, the potassium (K) DPAL, has not been extensively studied yet, in spite of its several advantages compared to Cs and Rb lasers. In particular, the K laser has higher quantum efficiency (99.6%) and can operate with low pressure noble buffer gases (He, Kr or Xe) [10], while Cs and Rb lasers can operate only with hydrocarbon buffer gases or with high pressure (several atmospheres) helium buffer gas. Both of these approaches have their disadvantages compared to the K laser. Hydrocarbon buffer gases can chemically react with alkali vapor and contaminate the gain medium with the reaction products (e.g. soot). High pressure Rb-He laser requires elevated temperatures and higher pump intensities that creates additional technical and fundamental problems especially when scaling to higher power levels. Only recently, a first demonstration of a CW diode pumped potassium laser buffered by atmospheric pressure helium was performed [11], and the slope efficiency achieved was not very high (about 25%). In this paper we present results of our experiments with a K DPAL operating in pulsed mode.

The K laser operates in a three level scheme (see Figure 1). The optical pump source excites the D2 line of potassium atom (766 nm) and lasing occurs on the D1 line (770 nm), which is only 57.7 cm^{-1} from the D2 line. To create a population inversion on the $4P_{1/2} \rightarrow 4S_{1/2}$ transition, a fast (compared to the $4P_{3/2}$ lifetime) population transfer from $4P_{3/2}$ to $4P_{1/2}$ energy states is provided by collisional mixing of these states by a buffer gas. The laser has a quantum efficiency of 99.6%, but the small separation of the pumped ($4P_{3/2}$) and lasing ($4P_{1/2}$) energy levels decreases a population inversion on the lasing transition and, hence, leads to lower gain compared to Cs and Rb vapor lasers. Lasers with a lower gain medium require a higher quality laser cavity, higher pump intensity and are very sensitive to intracavity losses. All parameters required for the small signal gain calculation for the K DPAL are provided in [11] and the calculated value is about 0.18 cm^{-1}, which is much smaller than the ones for Cs (4.5 cm^{-1}) and Rb (1.1 cm^{-1}). This means that the lasing threshold for the K DPAL has to be higher than the one for Cs and Rb DPALs.

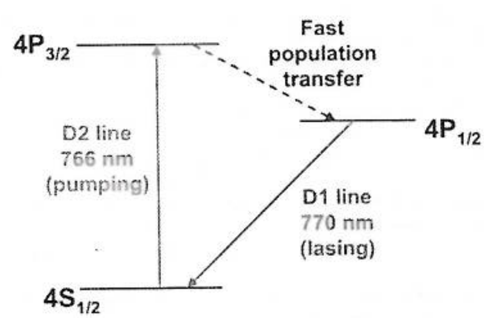

Figure 1. Potassium laser energy level diagram

2. Experimental apparatus and results

A diagram of the K DPAL is presented in Figure 2. We used an L-shape laser cavity with longitudinal pumping of the gain medium, similar to described in our previous experiments [10]. The 1 cm long K vapor cell had AR coated on both sides windows to minimize losses in

the cell for both the operation wavelength (770 nm) and the pump (766nm). The cell was filled with metallic potassium and 600 torr of helium at room temperature before being sealed.

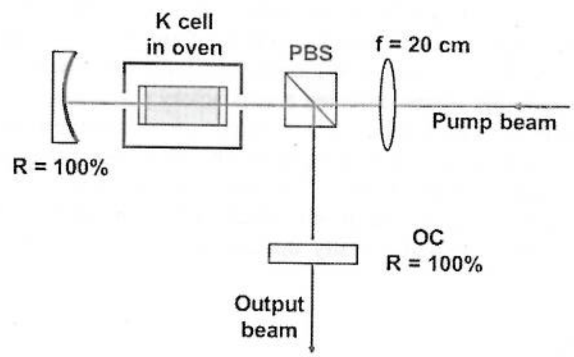

Figure 2. Diagram of the experimental setup.

The sealed cell was assembled inside an oven that could control the cell temperature while keeping its windows at about 5°C higher temperature than the cell body. The cell optimal operating temperature of 180°C was determined experimentally by measuring laser efficiency at different temperatures. The low signal absorption of the pump radiation in the K vapor cell at this temperature is close to 100% (see Figure 3).

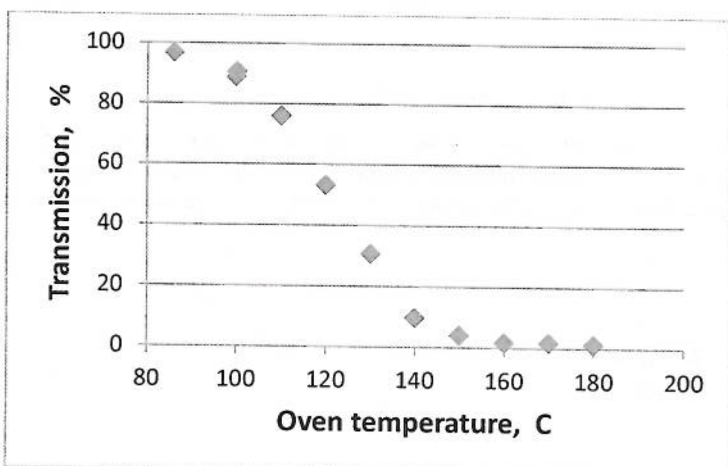

Figure 3. Experimental temperature dependence of the K vapor cell transmission for the low power pump radiation (several W/cm^2)

The K vapor gain medium was pumped by a diode laser stack operating at 766 nm. The stack emission line was narrowbanded to the value less than 20 GHz (FWHM) centered at 766nm using technique similar to described in [12]. The stack operated in pulsed mode with

pulse duration about 30 μs and rep rate 100 Hz. Maximum peak power of the pump delivered into the gain cell in these experiments was approximately 50W.

The stack's output beam had a rectangular cross sections with a vertical to horizontal sides ratio of about 4 : 1. To correct the beam and make it close to square before focusing into the gain medium, we used a system of cylindrical and spherical lenses with total focal length of about 20 cm. The beam was focused into the center of the K vapor cell and aligned collinearly with the laser cavity axis to provide longitudinal pumping. Such a combination of cylindrical and spherical focusing lenses provided a satisfactory pump beam size matching to the laser cavity mode size in the gain medium. The polarization of the pump beam was orthogonal to the laser beam polarization making it possible to separate the pump and lasing beams using polarization beam splitter (PBS). The stable 40 cm long laser resonator was constructed of a 50 cm radius concave mirror with 99.9% reflection at 770 nm and 766 nm and flat output coupler with an experimentally optimized 60% reflection at 770 nm (see Figure 4).

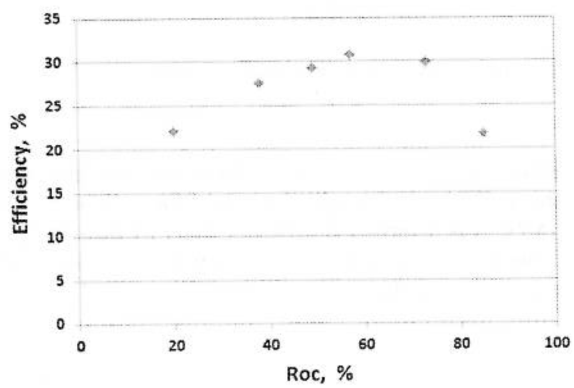

Figure 4. Optimization of the output coupler

The dependence of the K DPAL output peak power with respect to the pump peak power is presented in Figure 5. The lasing threshold appeared to be about 22 W or approximately 4 kW/cm^2. The slope efficiency was 52% and the total optical-to-optical conversion efficiency

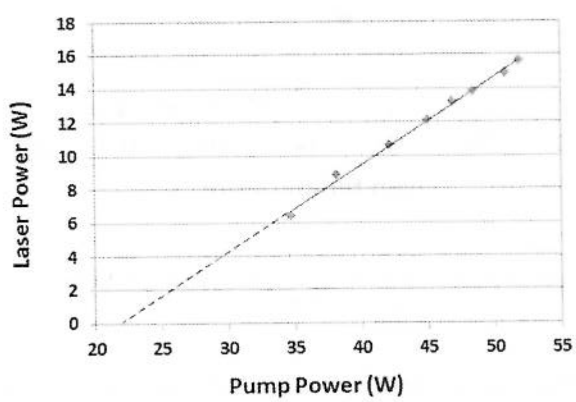

Figure 5. K DPAL output power dependence on pump power demonstrating 52% slope efficiency

was about 31%. The maximum output power obtained was about 16 W. These numbers could be even higher if to take into account mismatch between the pump beam and the cavity mode sizes difference. At the same time, the demonstrated efficiencies are significantly higher than those obtained in the same system operating in CW mode [11] that shows possible contribution of limiting effects, such as thermal lensing and ionization. The results of additional research aimed to study the contribution of these limiting effects and possible ways to mitigate them will be published in separate paper.

3. Conclusion

We have demonstrated a hydrocarbon free potassium DPAL operating in pulsed mode with a slope efficiency of 52% and optical efficiency 30% pumped by a narrowbanded diode laser stack. These numbers are significantly higher than demonstrated in [11] that show possible contribution of limiting effects, such as thermal lensing and ionization, when operating in CW.

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